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ISDN: State of the ART

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This report describes AIRMICS' on-going research in the area of ISDN. The report first describes those technologies that are key to the development of today's telecommunications system and then traces its evolutionary history. Next, a discussion of ISDN is given to include its description, benefits, costs, applications, and current status of implementation. The following section describes the research being conducted by AIRMICS, to include a description of its applications research testbed (ART). Finally, some concluding remarks are presented.

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This research was performed as an in-house project at the Army Institute for Research in Management Information, Communications, and Computer Science (AIRMICS), the RDTE organization of the U.S. Army Information Systems Engineering Command (USAISEC). The purpose of this report is to describe AIRMICS' on-going research in the area of ISDN. The report first describes those technologies that are key to the development of today's telecommunications system and then traces its evolutionary history. Next, a discussion of ISDN is given to include its description, benefits, costs, applications, and current status of implementation. The following section describes the research being conducted by AIRMICS, to include a description of its applications research testbed (ART). Finally, some concluding remarks are presented. This research report is not to be construed as an official Army position, unless so designated by other authorized documents. Material included herein is approved for public release, distribution unlimited. Not protected by copyright laws.

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ISDN: State of the ART

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I. Introduction

Perhaps the most important change in the Army's telecommunications system over the next ten years will be its evolution to an Integrated Services Digital Network (ISDN). This occurs as part of a worldwide trend toward a fully integrated digital telecommunications system. The driving forces behind this evolutionary change are the rapid advances in computer and data communications technologies, the increasing demand for improved information services (e.g., voice, data, and video), and the economic advantages of integration.

The U.S. Army Institute for Research in Management Information, Communications, and Computer Sciences (AIRMICS) is the research arm of the Information Systems Engineering Command (ISEC) which is subordinate to Information Systems Command (ISC), headquartered at Fort Huachuca, Arizona. The purpose of this paper is to describe AIRMICS' on-going research in the area of ISDN. The following section introduces those technologies that are key to the development of today's telecommunications system and then traces its evolutionary history. Next, a discussion of ISDN is given to include its description, benefits, costs, applications, and current status of implementation. The following section describes the research being conducted by AIRMICS, to include a description of its applications research testbed (ART). Finally, some concluding remarks are presented.

II. Key Technologies

The evolution of today's telecommunications system is based on two technologies: *transmission* and *switching*. Figure 1 shows the diagram of a general telecommunications

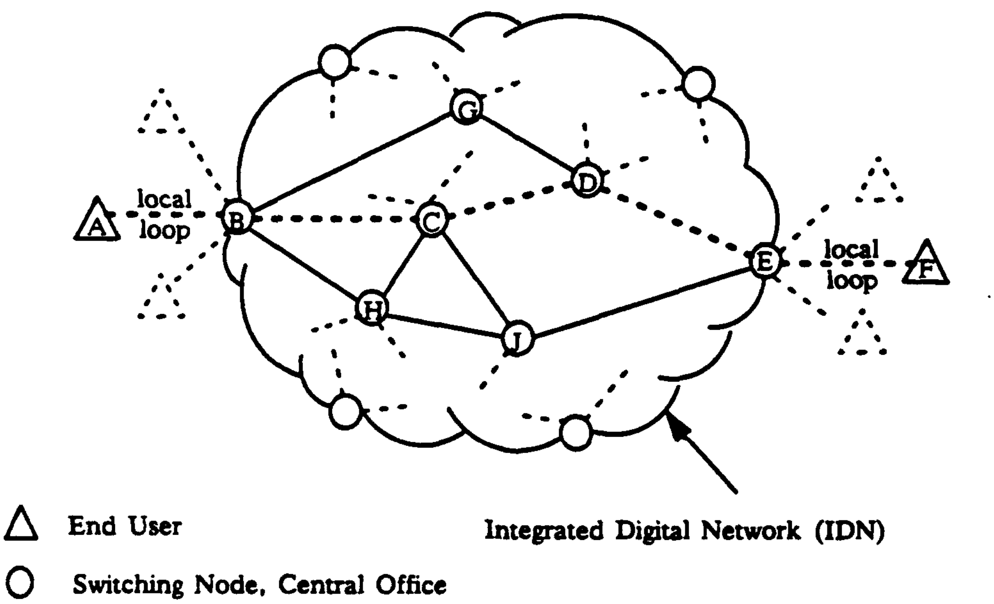

Fig. 1 Network Example

network where the circles represent switching nodes (e.g., telephone switching office) and the lines connecting the circles represent transmission paths (e.g., telephone cable). When a telephone call is made, the call is initiated at the end user's premises (A) and is transmitted over the telephone line (local loop) to the local switching office or central office (CO) (A-to-B). At the CO, the call is switched or routed onto the appropriate transmission path for transmission to the next switching node (B-to-C) . The telephone call continues to travel through the network in this alternating fashion, transmission from switch to switch, then routing within the switch, until the call is eventually received by the intended receiver (e.g., path ABCDEF).

Transmission refers to the act of sending information over some medium (e.g., telephone wire, optical cable, radio link) to the intended receiver. Information transmission can be performed by either analog or digital techniques. Analog techniques employ continuous-time waveforms to represent information, whereas digital techniques use discrete-time waveforms which are usually binary in nature (i.e., 1's and 0's), (Fig. 2). Voice, for example, is usually transmitted by analog transmission techniques, while computer data is usually transmitted by digital transmission techniques. Increasingly, however, digital is becoming the preferred method of transmission for both analog and digital information. Digital is preferred because it is a more robust transmission technique; allows for more efficient storage; is capable of using very powerful digital signal processing techniques (e.g., echo cancellation, data compression, firmware control of switching, and encryption); and is becoming less costly as the technology advances [1].

Switching refers to the act of routing the sender's message through the network to its proper destination. Switching is necessary for both economical and practical reasons. Without it, the alternative would be to provide every end user with a separate communications path to every other potential end user. This alternative becomes very complicated and expensive very quickly as the network population size increases. The two switching techniques considered here are circuit switching and packet switching. Assume again in Fig. 1 that we are making a telephone call. In circuit switching, a dedicated communications path or circuit is established between the transmitter and receiver for the entire duration of the call (e.g., path ABCDEF). The particular network circuit selected depends on the network conditions at the time the call is made and the call set-up procedures in use. When the network is too busy and a call cannot be completed, the call is said to be blocked. Blocking delay, rather than the time it takes for the call to actually travel through the network (transmission delay), limits network performance for circuit switched networks [2]. In packet switching, our telephone call is divided up into smaller segments called packets and is sent through the network. However, no dedicated circuit is established. Instead, the network routes packets from one switching node to the next, in a store-and-forward fashion, possibly over multiple paths depending on the network conditions and the routing protocols used. In Fig. 1, for example, one packet may travel path ABCDEF; the next packet may travel ABGDEF. Where circuit switching dedicates a particular path through the network for each telephone call being made, packet switching shares the network's communications paths among all telephone calls being made. Note that as packets arrive at each switching node, they are queued up for routing to the next appropriate node. The cumulative effects of this queueing delay cause relatively longer, nonuniform transmission delays than is experienced with circuit switching. As a result, transmission delay, as opposed to blocking delay, limits performance in packet switching networks.

The different switching techniques, discussed above, are necessary to satisfy the different communication requirements of voice, data, and video. In general, circuit switching is used for real-time applications like voice and video which require small transmission delay and tolerate moderate transmission error rates. On the other hand, packet switching is more appropriate for bulk data communications applications (e.g., host-to-host communications) which can tolerate moderate delay but require low transmission error rates. Packet switching is also more efficient for interactive data communications (e.g., human-to-computer communications) which has a bursty characteristic. Here, a bursty user is one who transmits short bursts of data at a high data rate in a sporadic fashion. Circuit switching of bursty type data results in an under utilized dedicated circuit because the circuit remains idle most of the time [3]. As advances in digital technology make packet switching a viable switching alternative for voice and video applications, the evolutionary trend is toward a network which operates with very fast packet switching for all types of network traffic [4,5].

III. Historical Perspective

The theme of the telecommunications system's evolutionary history has been one of integration, occurring first with the transmission of services (e.g., voice, data), next with the switching of services, and, in the near future, with the accessing of services. Prior to the

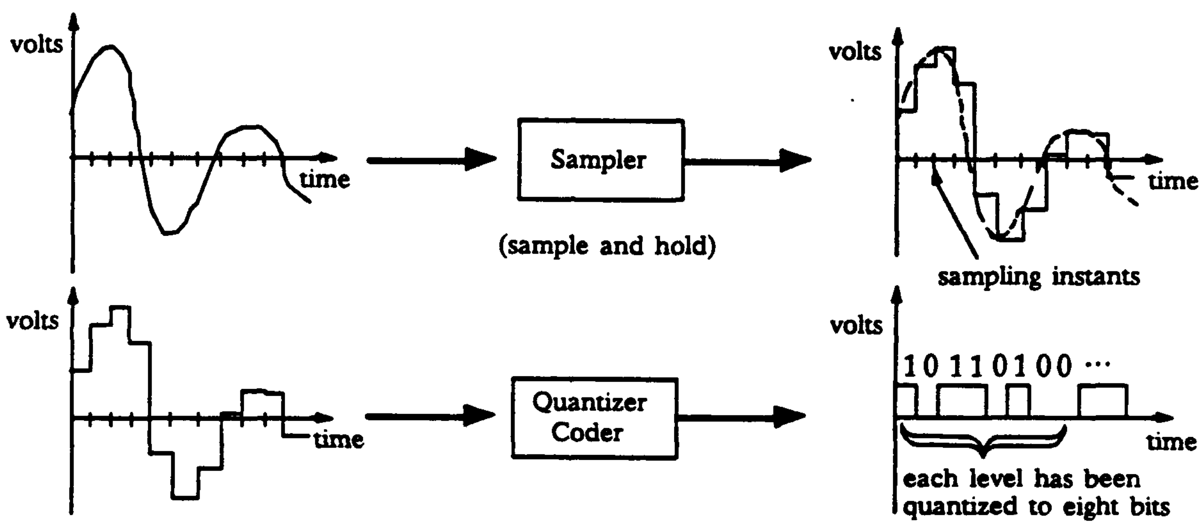

Fig. 2 Analog-to-Digital Conversion

1960's, the nation's telecommunications system provided only a few services (e.g., telephone and telegraph) over separate networks by analog transmission and switching techniques. Over the last three decades, the increasing use of computers and advancing digital technology promoted the increased use of digital, instead of analog, transmission techniques. In 1962 the digital transmission of voice became commercially practical and allowed for the transmission of voice and data over the same transmission medium. Pulse code modulation (PCM) was the transmission technique used. Here, each voice channel is sampled 8000 times a second, and each voice sample is quantized to eight bits, for a total bit rate of 64 kilobit per second (kbps). An example of this analog-to-digital conversion process is shown in Fig. 2. This PCM data rate serves as the basis for the digital transmission rates used today. Note that the commonly referred to 56 kbps transmission rate results when a few bits are used for signaling purposes. The first commercial carrier (T1 carrier) was composed of 24 such voice channels, for a transmission rate of 1.544 megabits per second (Mbps).

Although the introduction of PCM allowed both data and voice to share the same transmission medium, each had to be converted back to analog format prior to the switching operation. It was not until the mid 1970's that the first commercial digital switch was introduced, the Western Electric 4ESS (1976). Digital switching eliminated the inefficient digital-to-analog conversion required for switching and allowed for the integration of the transmission and switching processes. Today, this integrated digital transmission and switching network is referred to as the Integrated Digital Network (IDN) (Fig. 3). Note, however, that while the transmission and switching processes are both digital, voice and data networks remain logically separated because of their differing requirements for network delay and transmission error rates. The transmission and switching processes are integrated for a particular service, but not over multiple services. Also note that, although a significant portion of the IDN has been installed, end user access to the network (i.e., the local loop) remains primarily analog [6].

As with the nation's telecommunications system, the Army's telecommunications system is experiencing a similar evolution. The current system which provides such services as voice (AUTOVON), secure voice (AUTOSEVOCOM), and record message traffic (AUTODIN) is transitioning to a system of networks which provide integrated transmission and switching. AUTOVON and AUTOSEVOCOM are transitioning to the Defense Switched Network (DSN) which will provide integrated facilities for voice and data communications by providing digital transmission facilities and by automatically selecting circuit or packet switching services as required. AUTODIN and the various post/local area networks are transitioning to the Defense Data Network (DDN) which will provide a worldwide packet data communications network separate from the DSN but share the same transmission resources and be capable of intercommunicating via the (ISDN) packet switching capabilities of the DSN switches. Additionally, the Defense Message System (DMS) will eventually provide message service between organizational elements and message service between individuals in an electronic mail fashion.

The next step in the evolution of today's telecommunications system is from a system of smaller separate networks (Fig. 3) to an integrated system of networks (Fig. 4). Because today's networks remain logically separate, an end user needs to have a separate access line to each network in order to use its services. The principle exception to this separation is point-to-point data transmission using voiceband data modems or other data over voice techniques. The next evolutionary step is to provide the end user with a single access line to all services. This next step is to ISDN.

IV. Integrated Services Digital Network (ISDN)

ISDN is simply a standard way to replace existing local loop analog circuits with local loop digital circuits. As such, ISDN extends the digital connectivity of the IDN to the end user's premises. Where the current IDN provides telecommunications services over many different networks, ISDN will provide access to these services over a single network – the telephone network. Note that ISDN is not a sudden change of the entire system, but rather an evolution of the existing system. As defined by the International Telephone and Telegraph Consultative Committee (CCITT) ISDN is [7]

> *a network evolved from the telephony Integrated Digital Network (IDN) that provides end-to-end digital connectivity to support a wide variety of services, to which end users have access by a limited set of standard multipurpose end user interfaces.*

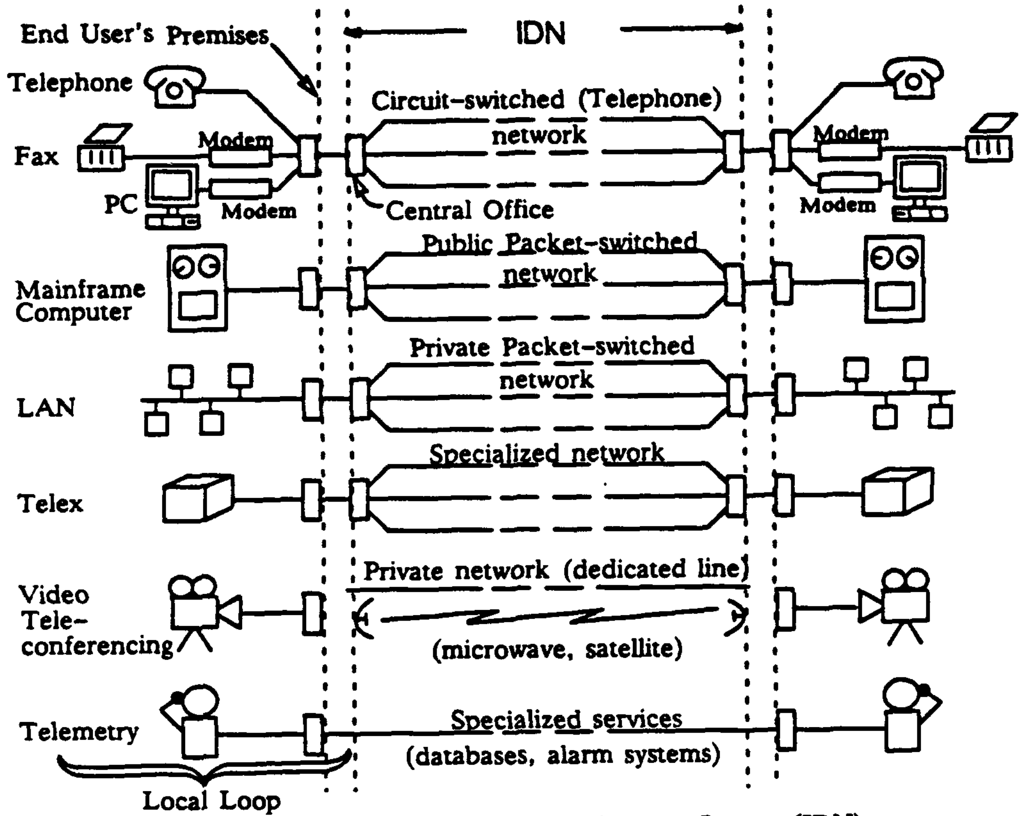

Fig. 3 Current Telecommunications System (IDN)

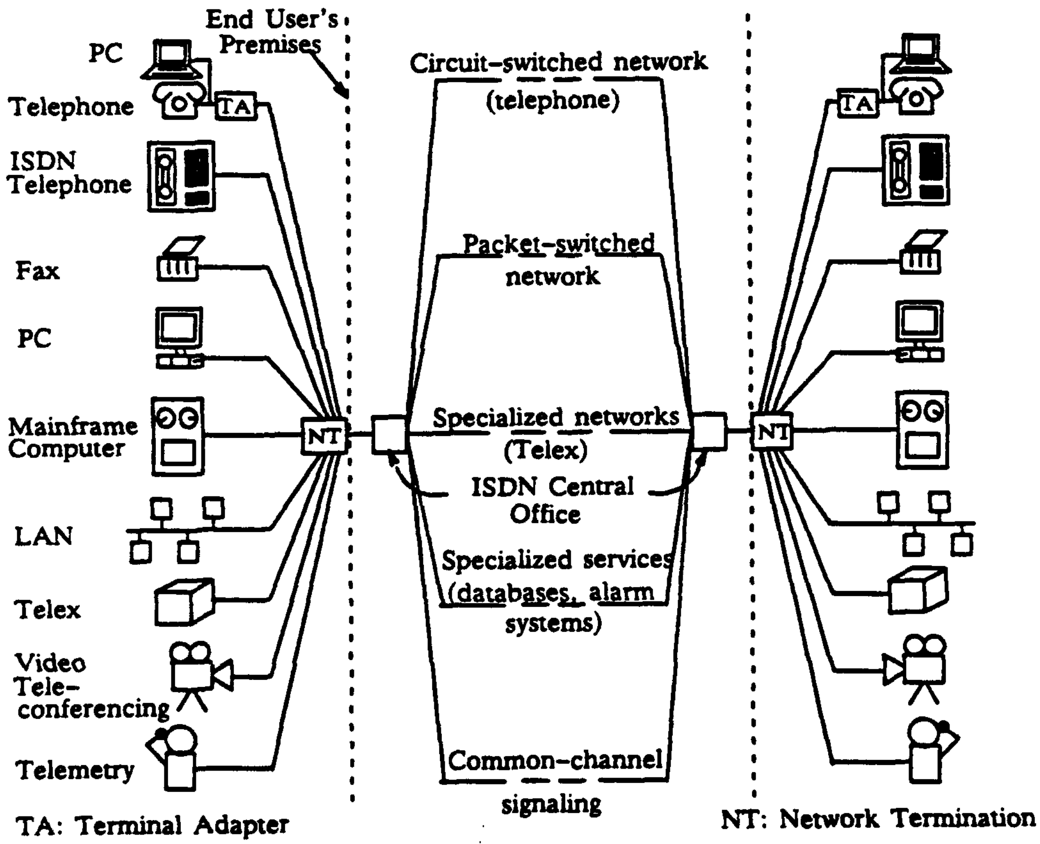

Fig. 4 Future Telecommunications System (ISDN)

When implemented, ISDN will provide the following capabilities:

- Access and service integration which minimizes the number of devices on an end user's desk. Potentially, one standard voice-data-video terminal can replace the 3 or 4 devices (e.g., telephone, data terminal, and workstation) which are currently sitting on the end user's desk.

- End-to-end digital connectivity which eliminates the need for a modem and provides the end user with both circuit- and packet- switched, high speed, digital telecommunications.

- Two-way communication which effectively doubles the number of telephone lines available to the end user and allows simultaneous transmission and reception of voice, data and video over the same telephone line.

- A limited set of standardized user-network interfaces which allows terminal equipment to be used at any location in the network (i.e., equipment portability).

- End user control of service features (i.e., call-by-call service selection) which reduces costs (e.g., trunk charges, and administrative and maintenance charges) and increases operational efficiency.

Ideally, when fully implemented, ISDN will allow end users to use the capacity of the network (i.e., services, bandwidth, etc.) much like we use commercial power today. End users will be able to plug their communications terminals into any communications outlet and consume as much network capacity as their particular applications require.

Depending on the level of service required, two ISDN access rates are available: *basic* and *primary*. The basic rate is intended to meet the needs of the end user and is composed of two 64 kbps Bearer (B) channels and one 16 kbps Data (D) channel, commonly referred to as 2B+D (Fig. 5) . Having two B-channels (logical telephone lines) effectively doubles the

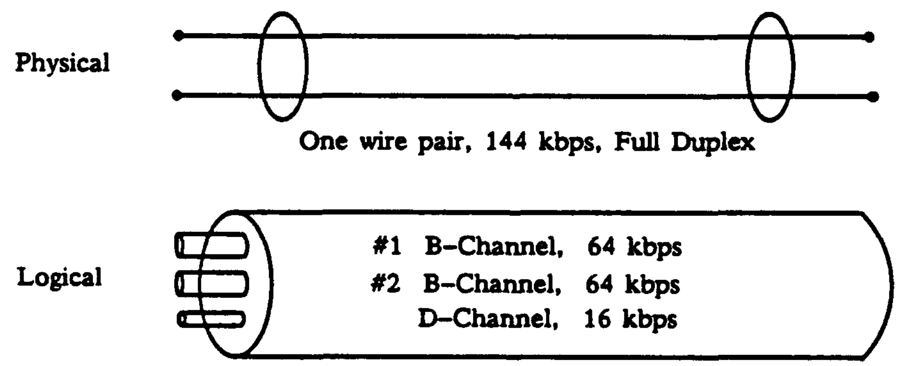

Fig. 5 ISDN Basic Rate Access

number of telephone lines for each end user. The B-channels provide for circuit-switched voice service, and both circuit-switched and packet-switched high-speed data services such as bulk data transfer, facsimile, and slow scan video. Supplementary services provided over the B-channel include existing Centrex-like services such as call waiting and call completion to a busy end user, and ISDN services such as calling line identification (CLID) [8]. The

D–channel is used to control the B–channels and to provided low–speed data teleservices such as telex, telefax, email, and telemetry for emergency services and energy management. Additionally, as with the existing telephone system, extensions can be madı 'rom a basic rate interface (BRI) connection in a passive bus arrangement. In this arrangement, once a B–channel is acquired by a particular user, it cannot be shared by other end users. The D–channel, however, is shared among all users in a statistical manner. Here, a particular end user listens to the D–channel before transmitting. If someone is transmitting, then the end user waits a predetermined amount of time before re–attempting to transmit, much like carrier sense multiple access (CSMA).

The primary access rate is composed of twenty–four 64 kbps channels (23B+D) and is intended for business type applications or for connection to large clusters of end user devices supported by private branch exchanges (PBX) or local area networks (LAN). The 23B+D channels plus framing bits result in a composite transmission rate of 1.544 Mbps which is designed to operate on T1 lines, mentioned earlier.

Besides easier access to more services, other potential benefits of ISDN include higher speed data transmission (64 kbps is 53.3 times faster than a 1200 bps modem), better quality transmission through the use of advanced digital signal processing techniques, and improved network management through the use of common channel signaling (D–channel, Signaling System 7). Transmission security is increased by voice recognition quality speech and the use of recent developments in communications security such as embedded cryptography in end user equipment and advanced cryptographic keying. Finally, network survivability and interoperability are enhanced through the increased interconnectivity and flexibility afforded by standardized interfaces and equipment [9].

The costs for these benefits are difficult to assess. Costs are minimized by providing multiple services over a single access line and by minimizing the number of terminal devices. However, costs are increased by the requirement for upgraded equipment such as ISDN switches, ISDN terminal equipment (network termination equipment, terminal adapters, ISDN telephones, adapter cards for PCs, etc.), and software to run various applications. Additionally, the costs of network management, operation and maintenance, and training for this new technology are not yet fully understood.

ISDN seems to be following the life cycle of most new technologies (Fig. 6). Currently, its infrastructure is inadequate and applications are too few in number. Much like the automobile marketplace of the 1910s, in which the lack of roads provided little incentive to the horse and buggy owner to buy an auto, the ISDN end user finds that the ISDN marketplace has very limited geographic coverage. Also, the ISDN marketplace is much like the television marketplace of the 1940s, in which the lack of television programming provided little incentive for people to buy TVs, and the lack of TV viewers provided little incentive for TV program development. Potential ISDN users see too few applications, and ISDN applications developers see too small a market.

In spite of these growth problems, ISDN is finding increasing use in three broad application areas: voice, data, and integrated voice/data. The primary voice–only application being used today is analog key telephone replacement. Despite the initial cost and the moderately higher tariff rates, in the long term, ISDN provides for reduced cost by minimizing the costs associated with office moves and reorganizations, easier access to a greater number of service features for increased productivity, and flexibility for future data and voice/data integration needs.

Typical data–only applications include PC networking, LAN bridging, and network backup and peak load support. In general, it is not cost effective to replace existing data networks

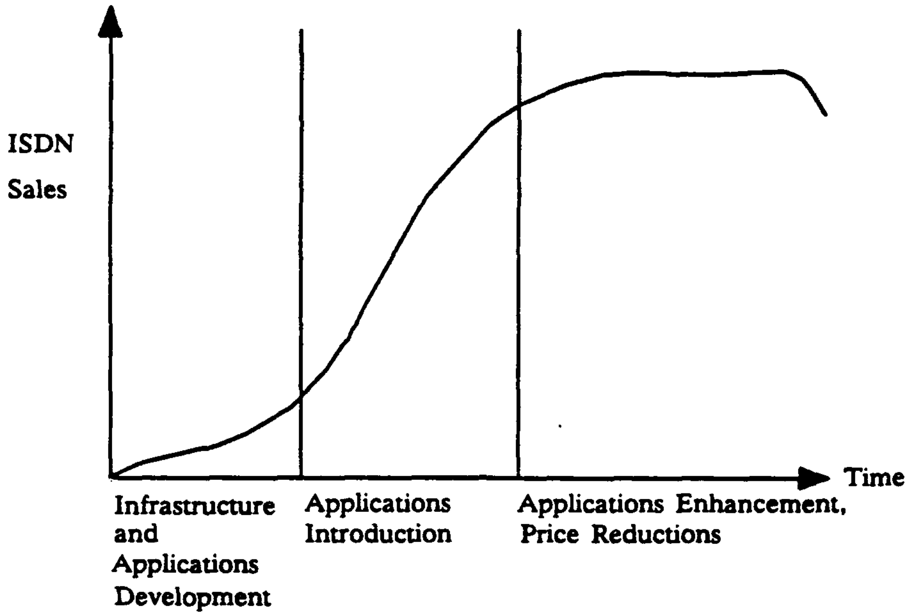

Fig. 6 Technology Life Cycle

(e.g., LANs) with ISDN. Additionally, there is no mature network management system for ISDN LANs as there is with current LAN technology. However, if there is no LAN in place, then ISDN becomes a cost effective alternative for the same reasons as discussed above for analog key replacement. ISDN is also cost effective for LAN bridging. Relative to dedicated-line LAN bridging, ISDN LAN bridging becomes more cost effective and efficient as the number of interconnected LANs increases, as their interconnection distance increases, and as their inteconnection traffic becomes more bursty. Finally, ISDN provides a very cost effective alternative for data network backup and peak load support. Pre-ISDN choices are to purchase costly redundant links, or use slow dial-up lines in case of network failure or overload. With ISDN, B-channels can be used dynamically, so that charges are levied only when they are used.

Voice/data integration is the primary benefit of ISDN. This capability is being used in the telemarketing industry to enhance productivity by providing customer service, demographic analysis, and incoming/outgoing call management. In incoming call management, for example, CLID is used to pair an incoming call with an existing data base so that the caller's file can be displayed at the moment the call is answered. CLID can also be used to perform automatic call back which allows unanswered calls to be returned automatically. Screen sharing is another popular application. Here, two PC users can communicate by voice, share a screen of information, and access a shared data base (e.g., an electronic directory), all with a single telephone call connection (2B+D). Other typical applications include Group IV facsimile which allows end users to communicate by voice and exchange facsimile simultaneously, messaging services which allows messages to be processed electronically, and wideband audio conferencing which provides for very high quality voice communication (i.e., nearly as good as FM radio).

The deployment of ISDN in the U.S. civilian sector is progressing at a steady rate, but its success has been limited to many isolated locations or 'ISDN islands'. Since the first major ISDN trials in 1986, hundreds of locations throughout the U.S. have installed ISDN to support particular applications. However, these ISDN islands provide only localized ISDN service. There is little interconnectivity between U.S. cities. AT&T Co. and U.S. Sprint Communications Co. are just beginning to establish ISDN interconnectivity between the many cities they service. AT&T, for example, has long-haul ISDN services at the primary rate between only 18 U.S. cities.

Concurrent with ISDN developments in the commercial sector, there have been a few Army ISDN trials. The most notable of these is at Redstone Arsenal, AL, where approximately 300 of the currently planned 512 ISDN lines have been installed. ISDN service is being provided to the Missile Command (MICOM) Headquarters and its numerous directorates and is being used for voice and PC networking applications. Redstone is also evaluating video teleconferencing with ISDN. In another Army trial, the Personnel Information Systems Command (PERSINSCOM), Alexandria, VA, is evaluating an ISDN application which allows personnel managers to retrieve and to view a soldier's personnel records during the process of the telephone call. The Air Force and the Navy are also involved in their own ISDN trials at Barksdale Air Force Base, LA, and Pensacola, FL, respectively.

Unfortunately, the full benefit of ISDN will not be realized until it is more widely accessible and more useful than it is today. Expansion of the ISDN infrastructure (i.e., the number of lines, switches, and terminal equipment deployed) has been limited by the lack and incompatibility of ISDN switches and terminal equipment. Roughly half of existing switches are not digital or are not capable of supporting ISDN services. The remaining service life of non-ISDN switches ranges from 5 to 10 years which makes their immediate replacement too costly. Of those ISDN switches currently deployed, many are incompatible (e.g., the AT&T 5ESS versus the Northern Telecom DMS100). Equipment incompatibility is due in large part to the slowness in protocol development for terminal equipment (ISDN telephone sets) and for interswitch communications (Signaling System Number 7).

Applications development has been limited because developers see too few end users, while end users are reluctant to embrace ISDN because of the lack of applications. Why? Primarily because ISDN offers little more than what is currently available and at higher cost. There are numerous cost effective alternatives to ISDN which have already been put into operation. In some cases, existing technologies are better suited to particular applications (e.g., existing LANs are better suited for data-only applications). No one *killer* application has yet been developed to cause a widespread demand for ISDN. In order to make effective use of this new technology, what is currently needed is for end user needs to be accurately assessed, for ISDN capabilities to be more fully understood, and for applications to be identified/developed which accurately match ISDN capabilities to end user needs. This is precisely the U.S. Army's mission at AIRMICS.

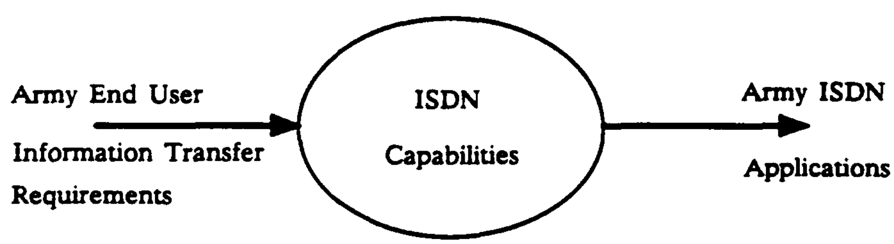

Fig. 7 Matching Army Needs to ISDN Capabilities

V. Applications Research Testbed (ART)

Because ISDN is the Army's future network configuration, it is important that the Army understand ISDN's capabilities and limitations so that it can make well informed decisions on when and how to transition to it. Toward this end, an applications research testbed (ART) has been established at AIRMICS. The primary objective of the ART is to determine how ISDN can best serve the information transfer needs of the Army (Fig. 7).

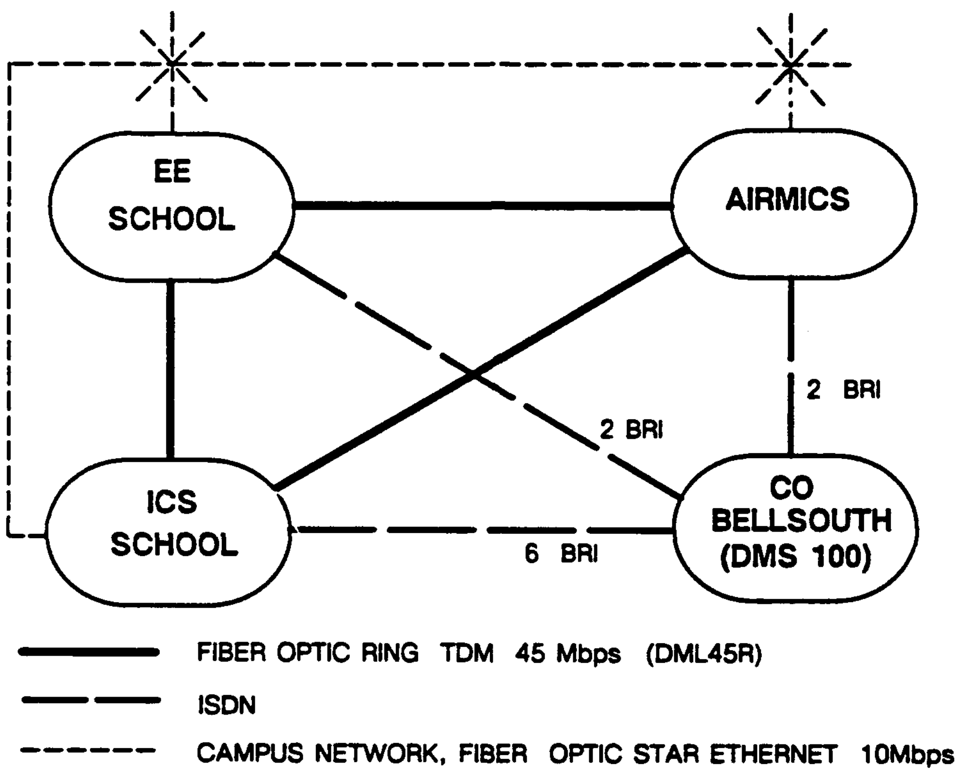

Fig. 8 ISDN Applications Research Testbed (ART)

The ART consists of four nodes which are interconnected by various types of transmission media, as shown in Fig. 8. Three of the nodes are designated as test sites and are located on the Georgia Tech campus at the School of Electrical Engineering (EE), the School of Information and Computer Science (ICS), and AIRMICS. The fourth node is a local BellSouth central office which interconnects the three test sites by extending a certain number of BRI lines to each site. Switching at the central office is performed by a Northern Telecom DMS 100 ISDN switch. Typically, each site is equiped with terminal equipment (e.g., ISDN telephones, data terminals), switching equipment (e.g., a PC configured to serve as an ISDN PBX, ISDN switch simulators), and testing equipment (e.g., ISDN protocol analyzers, load generation and measurement hardware/software). In general, the ART provides for three levels of connectivity: local connectivity within the test site, regional connectivity with other test sites on campus and within the Atlanta area, and national connectivity with other installations, academic institutions, and commercial activities. Additionally, full experimental freedom is provided by a totally isolated fiber optic ring network. Overall, the ART provides a rich and diverse environment for evaluating any number of ISDN network scenarios.

The research being conducted in ISDN is a joint effort between the government, industry, and academia: AIRMICS, BellSouth Enterprises, and the ICS and EE Schools at Georgia Tech. The research is currently entering the second year of a three-year program. During the first year of the research, analytic tools for performance testing were developed by the ICS and EE Schools. These tools include a character timer which can be used to analyze the performance of the D-channel for transmitting character data, an error injector which permits controlled errors to be injected into the line so that the network can be evaluated in a stressed environment (i.e., field use), and a packet-level timer which can be used to evaluate the packet handling capabilities of the B and D channels. These tools are currently being used to evaluate the relative merits of the various ISDN services (e.g., comparing the data transport capability of D-channel packet service versus B-channel switched service). Note that the focus of the research is not limited to performance testing. It also involves functional, conformance and interoperability testing. To date, numerous implementation problems and issues which relate to cost, interoperability, and integration have been uncovered and are the subject of separate progress reports. Research results also include a study of ISDN protocols and the preparation of an ISDN User's Handbook.

Presently, the research is expanding in scope to evaluate the suitability of the various ISDN services to support the Army's information transfer requirements. In particular, AIRMICS is investigating data access issues such as DDN access over ISDN, LAN access over ISDN, LAN bridging, ISDN as a LAN, and high speed file transfer. Video conferencing research issues include video telephony, multipoint video teleconferencing, and the feasibility of multi-media ISDN workstations. Other research topics include the development of a standard ISDN software interface and operational test specifications.

VI. Concluding Remarks

The objective Army information system of the future is a fully integrated digital telecommunications system that will be able to transmit multimedia information (voice, data, video, image, graphics) to people and machines worldwide as conveniently and reliably as voice is transmitted today. ISDN is the next step along the evolutionary path toward this fully integrated telecommunications system. Whether the Army successfully makes this step, or stumbles along the way, depends on how well it understands its end user's information transfer needs and ISDN's capabilities, and on how well they are matched. AIRMICS' role is to investigate these issues and to advise the Army on how ISDN can best serve the needs of the Army. The purpose of this article was to describe ISDN and discuss the Army's research efforts in this area. Future articles will focus on the results of our applications research.

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